DEVELOPMENT OF HPM NON-PROPAGATION WALLS: TEST RESULTS & AUTODYN 2D PREDICTIONS OF WALL EFFECTIVENESS

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26th DDESB Seminar
Doral Resort & Country Club
Miami, Florida
August 16 -18, 1994

ABSTRACT

The Naval Facilities Engineering Service Center is developing a new ordnance storage magazine that will reduce encumbered land and improve operational efficiency. Non propagation walls are being developed to prevent sympathetic detonation between munitions stored in adjacent cells. Design loads, wall response, and candidate wall effectiveness (effect on acceptor rigid body response), are predicted and compared to test results from one-third scale development tests and full scale certification tests. Planning for a full scale magazine certification test is also shown.

INTRODUCTION

Background

The Naval Facilities Engineering Service Center is developing a new ordnance storage magazine, the High Performance Magazine (HPM). The performance goals of the HPM are to reduce encumbered land and to improve operational efficiency. The concept uses cell walls and aisle walls to prevent propagation of an explosion in adjacent cells. This significantly reduces the Maximum Credible Event (MCE), reducing encumbered land by at least 80% and reducing safe standoff range by more than 60%. The non-propagation dividing walls also allow storage of non compatible ordnance in the same magazine. A new handling system, using an overhead bridge crane and universal straddle lift, provides improved operational efficiency.

The most important factor in the improved explosives safety performance of the HPM is the reduction in the MCE. For example, the explosive storage capacity of the Type II HPM is 295,000 pounds net explosive weight (NEW) but the MCE is no more than 30,000 pounds NEW in the storage areas and 55,000 pounds NEW in the shipping and receiving area. Inhabited building distance (IBD) is reduced from 3345 ft. to 1330 ft. (60% reduction in safe distance and 84% reduction in encumbered land area).

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1994**	2. REPORT TYPE	3. DATES COVERED **00-00-1994 to 00-00-1994**

4. TITLE AND SUBTITLE **Development of HPM Non-Propagation Walls: Test Results & Autodyn 2D Predictions of Wall Effectiveness**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Facilities Engineering Service Center,1100 23rd Street,Port Hueneme,CA,93043-4328**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM000767. Proceedings of the Twenty-Sixth DoD Explosives Safety Seminar Held in Miami, FL on 16-18 August 1994.

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**27**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

NFESC has shown that the HPM concept is feasible based on analytical modeling and test results. In FY93, NFESC conducted two explosive tests of full scale storage cells that demonstrated the non-propagation storage cell walls will prevent sympathetic detonation to MK82 bombs and M107-155mm projectiles. The non-propagation walls were designed using donor loads and wall response predictions from AUTODYN-2D model analysis. The modeling procedure had been developed during small scale parameter testing during FY92 and FY93. All wall development and certification testing is being conducted at NAWC, China Lake.

In FY's 94 to 96, NFESC will conduct additional full-scale explosive tests at NAWC, China Lake, to certify explosives safety of the HPM prototype design. These tests will be designed to certify compliance with explosives safety regulations for each maximum credible hazard scenario in the HPM.

Design of the non-propagation walls requires calculation of the donor load environment, wall response, and the wall effect on mitigating acceptor loads. The "hydrocode" AUTODYN (2D & 3D) is being used for these calculations.

Purpose

The purpose of this paper is to show the development of the non-propagation wall. Design loads, wall response, and candidate wall effectiveness (effect on acceptor rigid body response), are predicted and compared to test results. One-third scale development tests and full scale certification test results are summarized and compared to analytical predictions of rigid body acceptor response (acceleration & velocity).

Scope

Small and one-third scale wall tests were conducted to study the mitigation effects of wall designs on sympathetic detonation. Full scale wall tests were conducted in FY93 & FY94 to demonstrate the effectiveness of proposed prototype wall concepts. The small scale parameter study tests were reported at the 25th DDESB Seminar. Results of the one-third scale development tests and full scale demonstration tests are presented and compared with analytical predictions in this paper . Rigid body acceptor response data (acceleration and velocity) from instrumented acceptors are compared to AUTODYN predictions. AUTODYN load predictions, used to calculate wall response and corresponding acceptor impact velocities, are also shown. Predicted acceptor deformation and internal fill pressures are presented and compared to test results in the paper "Development of HPM Non propagation Walls: Test Results and DYNA3D Predictions of Acceptor Response" by L. Javier Malvar and K. Hager, 26th DDESB Seminar, Miami Beach, FL, August 1994. Current planning for a full scale magazine certification test, scheduled for FY96, is also shown.

ONE-THIRD SCALE DEVELOPMENT TESTS

Test Objectives

The basic objectives of the one-third scale development tests were :

(a) to obtain data to verify and improve analytical models and to predict donor loads, wall response, acceptor loads, and acceptor response,

(b) to show the mitigating effects of specific wall cross-sections on acceptor loads,

(c) to determine candidate prototype cell wall cross-sections for full-scale tests.

Test Setup

A typical setup of the four one-third scale development tests is shown in Figure 1 The tests were designed to show the effects of wall parameters on acceptor response, and to provide data to compare with analysis.

Table 1 shows the test wall dimensions and materials for the wall core and cover. Plywood was used to contain the wall core (sand and steel grit). Most walls used energy absorbing cover materials placed opposite the acceptor. The cover materials were composed of a chemically bonded ceramic (CBC) manufactured by CEMCOM Corp. The CBC material has a high void ratio (60% porosity) and is lightweight (35 to 50 pounds per cubic foot). CBC formulations used in the tests had nominal crushing strengths between 2000 psi (GC2 formulation) and 4000 psi (S5 formulation). Four wall cross-sections were evaluated in each test.

Two Mk82 bombs were used as the donor in each test. All donors were oriented parallel to the test walls with their center of gravity located two feet above the floor slab. The nominal explosive weight of a Mk 82 is 200 pounds.

Two instrumented inert M107-155mm projectile acceptors were located opposite each test wall. Each instrumented acceptor had two accelerometers in a self-contained Hardened Data Acquisition System (HDAS) provided, installed, and operated by the U.S. Army Waterways Experiment Station, Explosives Effects Division. The HDAS measured the rigid body response of the acceptors. WES analyzed the accelerometer data and provided acceleration, velocity, and displacement time histories.

Analysis

Analysis of the one-third scale cell wall tests included two-dimensional load predictions of wall loads and wall response, and one-dimensional predictions of wall and acceptor impact response. The one-dimensional analysis provided timely predictions of wall parameter effects on rigid-body acceptor response (acceleration and velocity). Wall parameter effects

studied include wall mass and material, wall cover strength and thickness, and acceptor orientation.

The wall response and pressure loads on the donor side of a typical test wall were calculated in a two-dimensional, finite difference euler mesh. A typical two-dimensional model is shown in Figure 2. Symmetry was used to model a test with two Mk82 donors. One Mk82 donor was model as a cylinder of TNT parallel to the test wall . A reflecting surface on the vertical line of symmetry solved the donor loads for a setup that included a mirror image of the model shown in Figure 2 (i.e. two Mk 82 bombs between two test walls). Figure 3 shows the pressure time-histories on the donor side of the wall at selected wall heights. Figure 4 shows impulse time-histories at the same locations. The donor weight and location were chosen to obtain one-third scale design loads (from the critical MK80 series bomb donors) on the test walls.

One-dimensional calculations provided reasonable predictions of acceptor loads, and rigid-body acceptor accelerations and velocities. Results of the analysis show the relative effects of wall parameters on acceptor response. The predicted rigid body acceptor accelerations were also used to size and calibrate the accelerometers placed in the 155mm projectile acceptors.

The test wall, energy absorbing cover materials, and acceptors were modeled with La Grange finite-difference meshes (see Figure 5). Impact-slide elements, on the mesh boundaries, calculated the contact forces between the meshes. The acceptors were modeled as steel cylinders with the same weight and outside diameter as the 155mm projectiles used in the tests.

Test Results vs. Analytical Predictions

Table 1 compares predicted and measured rigid body acceptor accelerations and velocities. The wall impact velocity is a function of core material (steel grit and sand) and core thickness (6", 8", and 12"). Predicted wall velocities ranged from 100 m/s for the 8" steel grit wall to 200 m/s for the 12" sand wall. The test wall cross-sections included different cover thicknesses (0", 3", 6", and 12") and nominal cover strengths (GC2: 2000 psi, and S5: 4000 psi).

8" Steel Grit Wall with GC2 Cover. Lines 1 through 4 in Table 1 show predictions and measurements for the first test. Acceptors were oriented perpendicular to the walls. Predicted and measured accelerations were significantly reduced with increasing cover thickness. In general, measured peak velocities (as expected from predictions) varied little between acceptors. Acceptor four, opposite a steel grit core with no energy absorbing cover, showed an unexpected large peak velocity. Since there was no energy absorbing cover to absorb the initial high shock loads, the accelerometer may have been damaged during initial wall impact.

12" Sand Wall with GC2 Cover. Comparisons of predictions and measurements for test two (lines 5 through 8) show the same trend of enhanced mitigation of acceptor accelerations with increasing cover thickness.

<u>8" Steel Grit and 12" Sand Wall with S5 Cover</u>. These tests (lines 9 through 12) repeat the wall cross-section dimensions of tests one and two. However, the S5 CBC wall cover has a higher crushing strength than the GC2 CBC used in tests one and two. Accelerations were again reduced with increased cover thickness. Accelerations were generally higher with the S5 CBC than with GC2 CBC.

<u>6" and 8" Steel Grit Walls with GC2 and S5 Covers</u>. Test four (lines 13 through 16) shows effects of wall parameters on acceptors perpendicular and parallel to the test walls. Acceptors one and two are oriented perpendicular to the 6" steel grit wall (with 6" of S5 cover and no cover). The 6" and 8" steel grit walls (with 6" of S5 cover) produce similar acceptor accelerations and velocities. The accelerometers in acceptor two failed to record any data. Acceptors three and four are parallel to the 8" steel grit wall. Acceptor three is located between the test wall and acceptor four. The accelerometers in acceptor three failed to record any data. Predicted and measured accelerations in acceptor four indicate that acceptors parallel to the test wall suffer the harshest loads because of their greater surface area and from acceptor to acceptor impact.

Findings

Figure 6 shows the effects of wall core (12" sand at 100 psf and 8" steel grit at 200 psf) and wall cover thickness (0", 3", 6" and 12" of GC2) on measured accelerations. Without any wall cover, the steel grit wall caused higher measured accelerations in the acceptor than the sand wall. The higher impedance of steel grit countered the benefits of lower wall velocity. The advantage of the higher mass steel grit wall was realized, however, with the use of an energy absorbing cover.

Acceptor impact accelerations were mitigated by both increasing wall mass (by reducing wall velocity and kinetic energy) and increasing cover thickness (by lowering peak impact pressure and increasing strain energy capacity). Measured peak accelerations converged, independent of wall mass, with increasing cover thickness.

The one-dimensional analysis assumed that only the wall mass within the projected area of the acceptor transferred load to the acceptor. The granular wall core minimizes momentum transfer from outside this area. This assumption for calculating momentum transfer was verified by good correlation between predicted and measured acceptor response.

FULL SCALE WALL DEMONSTRATION TESTS

Test Objectives

The test objectives of the full scale wall demonstration tests were:

(a) to show that the HPM storage cell wall concept can prevent sympathetic detonation (SD) from a 10,000 pound NEW donor (48 - Mk 82 bombs) to acceptor ordnance (Mk 82 bombs

and M107-155mm projectiles). These are the worst case acceptors and donors for thick-skinned munitions.

(b) to verify analytical methods for predicting wall response, acceptor loads, and acceptor response,

(c) to show effects of key wall parameters on acceptor response. Four cell walls and two aisle walls were tested. Test variables included the energy absorbing cover strength (2000 psi and 4000 psi) and aisle (sand) wall thickness.

(d) to show the effect of acceptor orientation (Mk 82 perpendicular to the cell wall and parallel to the aisle wall) and acceptor type and fill (Mk82 with H6 fill and M107-155mm with Comp B fill) on acceptor response.

Test Setup

<u>Demonstration Test #1</u>

Test #1 used a 10,000 lb. donor (48 MK 82 tritonal filled bombs) , located between Cell Wall I and Cell Wall II, as shown in Figure 7a. The bombs were placed in a row four pallets long and two pallets high.

Cell Wall I was comprised of two 18" thick sections of GC2 acting as a wall cover around a 24" section of steel grit (270 pcf), as shown in Figure 7a. This prototype cross-section was 8' long and 6' high, as shown in Figure 7b. A 5' wide by 6' thick sand cross-section was placed at each end of the prototype wall to complete the cell. Cell Wall II was identical to Cell Wall I except that S5 was used as the cover material. The aisle wall, designed to separate the parallel pits inside the HPM, was an 8' thick sand wall with a 6' x 8' x 18" thick GC2 wall cover on the acceptor side.

The acceptor ordnance in Test #1 consisted of 34 inert MK 82 bombs and 48 inert M107-155mm projectiles. Their orientation, location, and designation are shown in Figures 7a, 7b and 7c. Several bombs and projectiles were instrumented with self-contained accelerometers for acquiring rigid-body motion data. MK 82 bomb numbers 2, 5, 14, 17, 25, and 26 contained accelerometers, as well as, M107-155mm projectile numbers 5, 6, 7, 21, 22, and 23.

<u>Demonstration Test #2</u>

As in the first test, a 10,000 lb. donor (48 MK 82 bombs) was located between Cell Wall I and Cell Wall II, as shown in Figure 8a. The Cell Wall cross-sections were the same as in Test #1 except that both walls used GC2. The aisle wall was reduced to a 6' thick sand wall (from 8' in Test #1) with a 6' x 8' x 18" thick GC2 wall cover on the acceptor side.

The acceptor ordnance in Test #2 consisted of both live Mk82 bombs (H6 filled) and M107-155mm projectiles (Comp-B filled). Twelve inert and 12 live MK 82 bombs were placed

perpendicular to Cell Wall I. Nine inert and 32 live M107-155 mm projectiles were placed opposite Cell Wall II. Six inert Mk82 bombs were placed parallel to the aisle wall. The orientation, location, and designation of the acceptor ordnance are shown in Figures 8a, 8b and 8c.

Analysis

Analysis of the full scale cell wall tests included two-dimensional load and response predictions for the non-propagation cell walls, and one-dimensional analysis to predict wall effects on acceptor rigid-body response (acceleration and velocity). Acceptor response predictions were also used to calibrate the accelerometers used in the acceptors.

Figure 9 shows a typical two-dimensional model of the full scale test setup. The donor is modeled as four rectangular areas of high explosive raised above the cell floor. The model includes a vertical line of symmetry which adds a mirror image of the model shown in Figure 9 (i.e. a row of Mk 82 bombs stacked two pallets high between two prototype cell walls). A cell cover is also placed over the cell.

The two-dimensional calculation provides wall loads and velocities as a function of wall height. Wall loads (69 psi-sec) and velocities (148 m/s), from the two-dimensional analysis, provide the initial conditions for the one-dimensional analysis. The approach for modeling the test walls and acceptors is the same as explained for the one-third scale tests.

Test Results vs. Analytical Predictions

Table 2 compares predicted and measured rigid body acceptor accelerations and velocities. The impact velocities of the cell and aisle walls are a function of core material and thickness (cell wall: 24" of steel grit", aisle wall: 96" of sand). Predicted wall velocities ranged from 140 m/s to 160 m/s.

<u>24" Steel Grit Cell Wall with 18" GC2 Cover</u>. Lines 1 through 5 and 13 through 14 in Table 2 show predicted and measured acceptor accelerations and velocities. In each test, the two Mk82 bomb accelerometers showed accelerations between the lower and upper bounds of the AUTODYN predictions. Measured and predicted peak velocities generally agreed.

Three instrumented M107-155mm projectiles measured accelerations significantly lower than the predicted values. One-dimensional, elastic models of the acceptors ignored the affects of plastic deformation and predicted conservative accelerations. The acceptor response measured during acceptor to acceptor impacts dominated the measured accelerations.

<u>24" Steel Grit Cell Wall with 18" S5 Cover</u>. S5 was only included in Test #1. Lines 6 through 10 show predictions and measurements for acceptor accelerometers. Results were similar to the steel grit wall with GC2 cover. However, accelerations tended to be higher than with the GC2 wall.

96" and 72" Sand Walls with 18" GC2 Cover. The thickness of the aisle sand wall was reduced by 25% between tests to determine the effects of wall mass on Mk82 rigid body response. Accelerations measured in Mk82 acceptors opposite the 96" sand wall were 70% of those measured in the 72" sand wall.

Findings

The 24" steel grit wall with 18" GC2 cover prevented sympathetic detonation of live critical acceptors (Mk 82 bombs and M107-155mm projectiles). Loads on aisle wall acceptors were reduced in proportion with increased wall mass (and thickness). Data from acceptors opposite the S5 covered walls were insufficient to confidently predict the relative effect of cover strength on acceptor loads. However predictions and acceptor deformations (see paper in this seminar by Malvar and Hager) indicate that GC2, with 2000 psi crushing strength, produced lower loads than the S5, with 4000 psi crushing strength.

FULL SCALE MAGAZINE CERTIFICATION TEST

In FY95, NFESC will conduct a full-scale magazine test at NAWC, China Lake, to certify explosives safety of the HPM prototype design. This test will be designed to verify prevention of sympathetic detonation of thin skinned (i.e. torpedo, missiles, mines) and thick skinned (i.e. bombs, projectiles) munitions from a 30,000 pound MCE in an HPM storage cell. This test will demonstrate mitigation of sympathetic detonation hazards from shock, fragment impact, wall debris impact, and crushing of acceptor ordnance from combined loads.

Test Planning

The test magazine will be an earth covered, reinforced concrete, box-shaped structure enclosing a weapons storage area in the HPM. Although full scale dimensions will be used, the test magazine will include only two of the four storage pits envisioned for the HPM. The weapons storage area consists of two storage pits, each 82 feet long by 20 feet wide by 15.5 feet deep. The two pits are separated by an aisle wall, 82 feet long by 9 feet wide by 15.5 feet high. Cell walls will be placed at specific locations in the pit to accommodate and separate different categories of stored munitions.

Plan and section views in Figure 10 show preliminary locations of aisle and cell walls separating the donor cell from four acceptor cells. A 30,000 pound NEW donor (144 H6 filled Mk82 bombs) in a 38.5' long x 20' wide x 15.5' deep cell representing the densest storage configuration, and highest donor loads, will be used. Critical acceptors for thick skinned (H6 filled Mk82 and Mk 84 bombs, Comp-B filled M107-155mm projectiles) and thin skinned (Mk55 and Mk65 mines, and Mk107 torpedo warheads) munitions will be placed in the acceptor cells. The selection and placement of acceptors is not final since test and analysis of worst case acceptors are not yet complete.

Analysis

Analyses are being conducted to predict donor loads and response of the non-propagation aisle and cell walls. A typical section view of the two-dimensional model is shown in Figure 11. The donor is modeled as two cylinders of TNT parallel to the aisle wall. Pit covers are shown over the acceptor and donor cells. All combinations of pit cover locations (open or closed) for adjacent cells are being considered to obtain the worst case test load.

Donor loads calculated for the different hazard scenarios will be compared to results of three-dimensional analysis using AUTODYN-3D. The comparison will help determine the worst case wall loads and response. The results of this comparison will be used in DYNA-3D analysis of acceptor response to wall-acceptor, acceptor-acceptor, and acceptor-magazine impacts (see paper by Malvar and Hager presented at this seminar for acceptor deformations and explosive fill pressures).

CONCLUSION

In FY92-FY94, NFESC has developed and completed a series of one-third and full scale test to demonstrate a feasible non-propagation wall design. During these tests, analytical procedures have been developed to evaluate wall concepts capable of reducing loads on acceptor munitions below thresholds for SD.

Desirable characteristics for a non-propagation wall have been determined in analysis and demonstrated in the test series. The wall cross-section must include a core composed of a dense granular material to reduce the wall's velocity and kinetic energy. Reducing the wall's velocity and kinetic energy mitigates the initial peak pressures and structural deformation of the acceptor. The granular material minimizes the momentum transfer from the wall to the acceptor. The low-strength, high porosity CBC wall cover limits the peak pressure during wall-acceptor impact and absorbs strain energy.

Good correlation was obtained between predicted and measured acceptor accelerations and velocities. This correlation provides confidence in the analytical approach for predicting donor loads, wall response, and acceptor response.

Two full scale cell wall tests demonstrated that the HPM storage cell and aisle wall concepts can prevent sympathetic detonation from a 10,000 pound NEW donor to worst case thick skin acceptor ordnance. The donor loads and acceptor orientations in this test are similar to those expected in the prototype HPM (the peak pressure and total impulse loads on the wall were equal to that expected in worst case HPM scenario because of the small cell size used in the full scale wall test). A full scale magazine test is planned in FY 95 to certify the HPM non-propagation cell and aisle wall designs.

Table 1. Predicted and Measured Aceptor Responses for One-Third Scale Cell Wall Tests.

Test	Donor	Wall Cross Section					Instrumented Accepor Accelerations					Acceptor Velocities	
		ID	Wall Core		Wall Cover		ID	Orient	Autodyn Predictions		Measured	Autodyn	Measured
			T	Core	T	Cover			low	high			
	(lbs)		(in)	(a)	(in)	(b)		(c)	(kg)	(kg)	(kg)	(m/s)	(m/s)
1	400	I	8	Steel	12	GC2	1	+		1.33	3.86	27	25
		I	8	Steel	3	GC2	2	+	2.07	12.00	7.7	32	32
		II	8	Steel	6	GC2	3	+		1.67	6	28	32
		II	8	Steel	--	----	4	+		27.00	32	37	86
2	400	I	12	Sand	12	GC2	1	+		1.74	4.8	30	30
		I	12	Sand	3	GC2	2	+	2.90	15.20	17	37	50
		II	12	Sand	6	GC2	3	+	2.50	4.50	9.2	33	23
		II	12	Sand	--	----	4	+		22.00	18	39	35
3	400	I	8	Steel	6	S5	1	+	2.07	12.00	5.8	35	27
		I	8	Steel	3	S5	2	+		27.00	14	34	50
		II	12	Sand	6	S5	3	+	2.90	15.20	15.5	38	29
		II	12	Sand	3	S5	4	+		22.00	23	38	32
4	400	I	6	Steel	6	S5	1	+	5.00	9.00	6	34	27
		I	6	Steel	--	----	2	+		27.00		45	
		II	8	Steel	6	GC2	3	//	5.00	-105.00		61	
		II	8	Steel	--	----	4	//		115.00	45	29	75

(a) Steel = S-170 Steel Grit (270 pcf); Sand = Sand (105 pcf)
(b) GC2 and S5 are chemically bonded ceramics made by CEMCOM Corp.
(c) Acceptor orientation key (+ = perpendicular to the wall, // = parallel to the wall)

Table 1. Predicted and Measured Acceptor Responses for One-Third Scale Cell Wall Tests.

Table 2.
Predicted and Measured Aceptor Responses for Full Scale Cell Wall Tests.

Test	Donor	Wall Cross Section					Instrumented Acceptor Accelerations					Acceptor Velocities	
		ID	Wall	Core	Wall	Cover	ID	Orient	Autodyn	Predictions	Measured	Autodyn	Measured
	(lbs)		T (in)	Mat'l (a)	T (in)	Mat'l	(b)	(c)	low (kg)	high (kg)	(kg)	(m/s)	(m/s)
F1	9861.0	G	24.0	Steel	18.0	GC2	B1	+	1.6	5.2	1.8	71.0	65.0
		G	24.0	Steel	18.0	GC2	B2	+	1.6	5.2	1.80	71.0	
		G	24.0	Steel	18.0	GC2	P1	//	4.4	68.0	16.0	63.0	
		G	24.0	Steel	18.0	GC2	P2	//	76.0	72.0	15.0	63.0	
		G	24.0	Steel	18.0	GC2	P3	//	75.0	75.0	17.00	63.0	
		S	24.0	Steel	18.0	S5	B3	+	4.10	6.10	3.4	80.0	60.0
		S	24.0	Steel	18.0	S5	B4	+	4.1	6.1	3.0	80.0	70.0
		S	24.0	Steel	18.0	S5	P4	//	13.0	115.0		70.0	
		S	24.0	Steel	18.0	S5	P5	//	140.0	120.0		72.0	
		S	24.0	Steel	18.0	S5	P6	//	150.0	150.0	15.00	73.0	
		A	96.0	Sand	18.0	GC2	B5	//		6.00	1.80	53.0	27.0
		A	96.0	Sand	18.0	GC2	B6	//		6.00	2.3	54.0	30.0
F2	9861.0	B	24.0	Steel	18.0	GC2	B1	+	1.6	5.2	3.4	71.0	80.0
		B	24.0	Steel	18.0	GC2	B2	+	1.6	5.2	2.80	71.0	75.0
		P	24.0	Steel	18.0	GC2	P1	//	4.4	68.0	15.0	63.0	90.0
		P	24.0	Steel	18.0	GC2	P2	//	76.0	72.0	14.0	63.0	140.0
		P	24.0	Steel	18.0	GC2	P3	//	75.0	75.0	11.00	63.0	60.0
		P	24.0	Steel	18.0	GC2	P4	//	4.4	68.0	7.80		35.0
		A	72.0	Sand	18.0	GC2	B3	//		6.00	2.7	53.0	40.0
		A	72.0	Sand	18.0	GC2	B4	//		6.00	3.8	54.0	48.0

(a) Steel = S-170 Steel Grit (270 pcf); Sand = Sand (105 pcf)
(b) Acceptor Key (B=Mk82 Bomb, P=M107-155mm Projectile)
(c) Acceptor orientation key (+ = perpendicular to the cell wall, // = parallel to the cell wall)

Table 2. Predicted and Measured Acceptor Responses for Full Scale Cell Wall Tests.

Figure 1. One-Third Scale Cell Wall Test #1 Setup

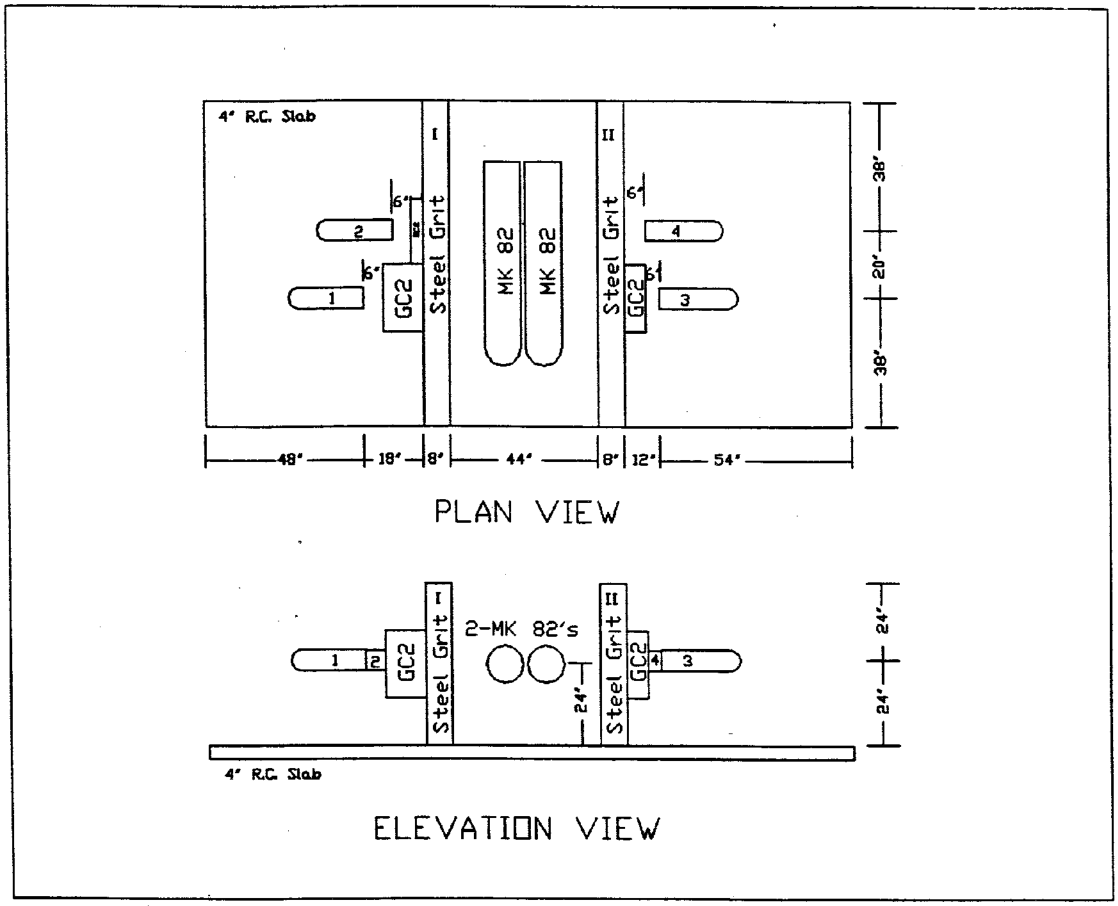


Figure 1. One-Third Scale Cell Wall Test #1 Setup

Figure 2. AUTODYN-2D One-Third Scale Test Setup

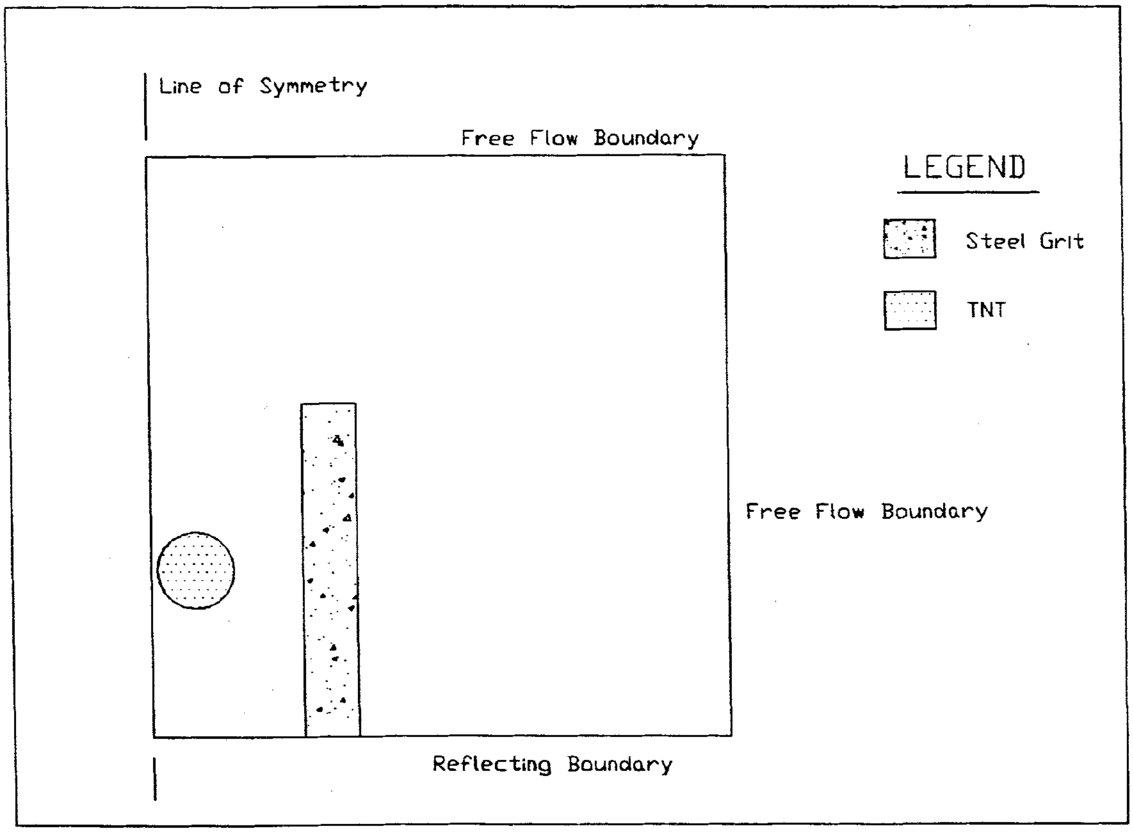


Figure 2. AUTODYN-2D Model One-Third Scale Test Setup

Figure 3.
Pressure time-history on donor-side of one-third scale testwall.

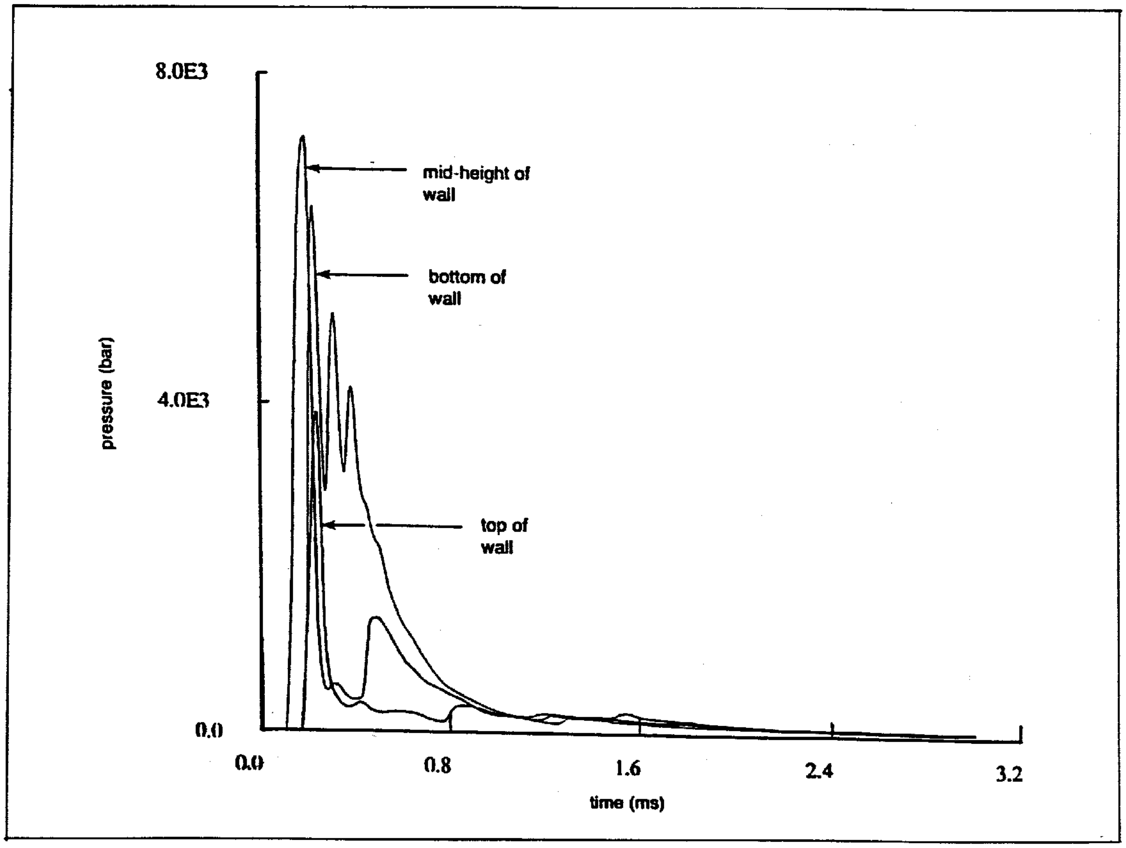


Figure 3. Pressure time-history on donor-side of one-third scale test wall.

Figure 4. Impulse time-history on donor side of one-third scale test wall.

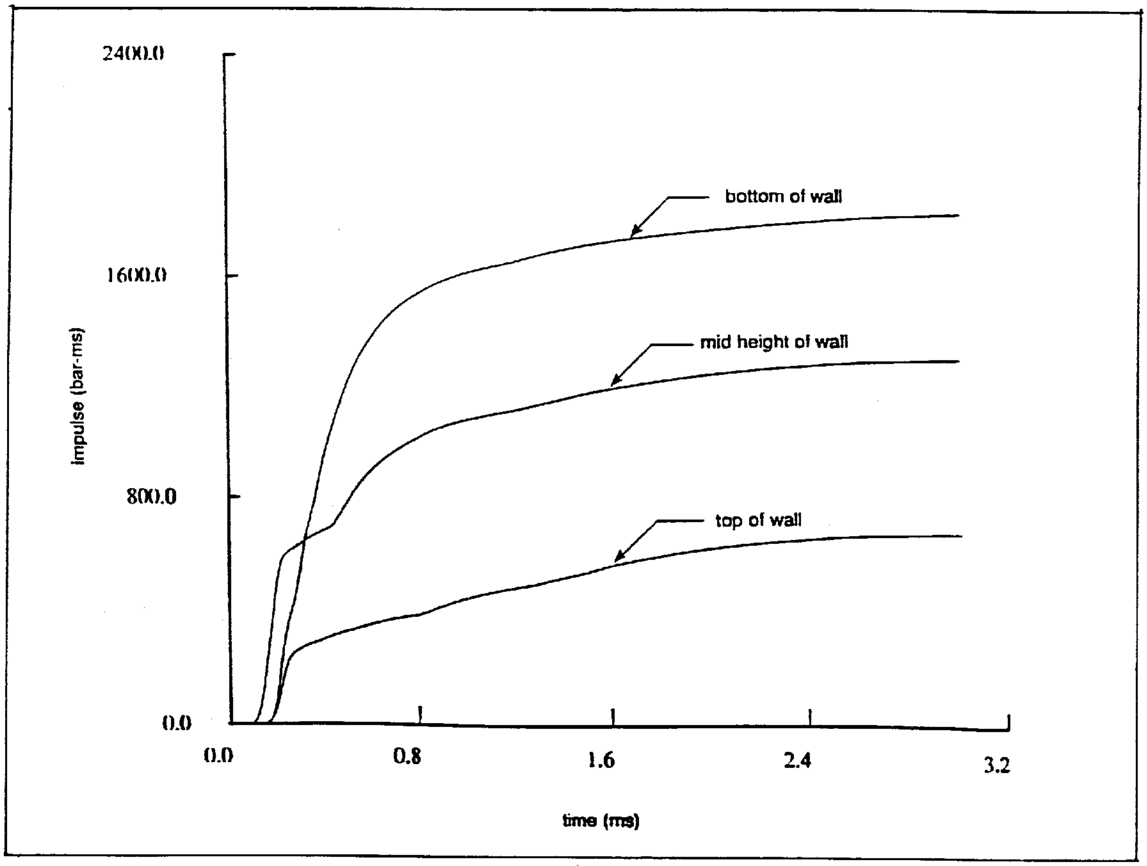


Figure 4. Impulse time-history on donor side of one-third scale test wall.

Figure 5. AUTODYN-2D One-Dimensional Model Setup .

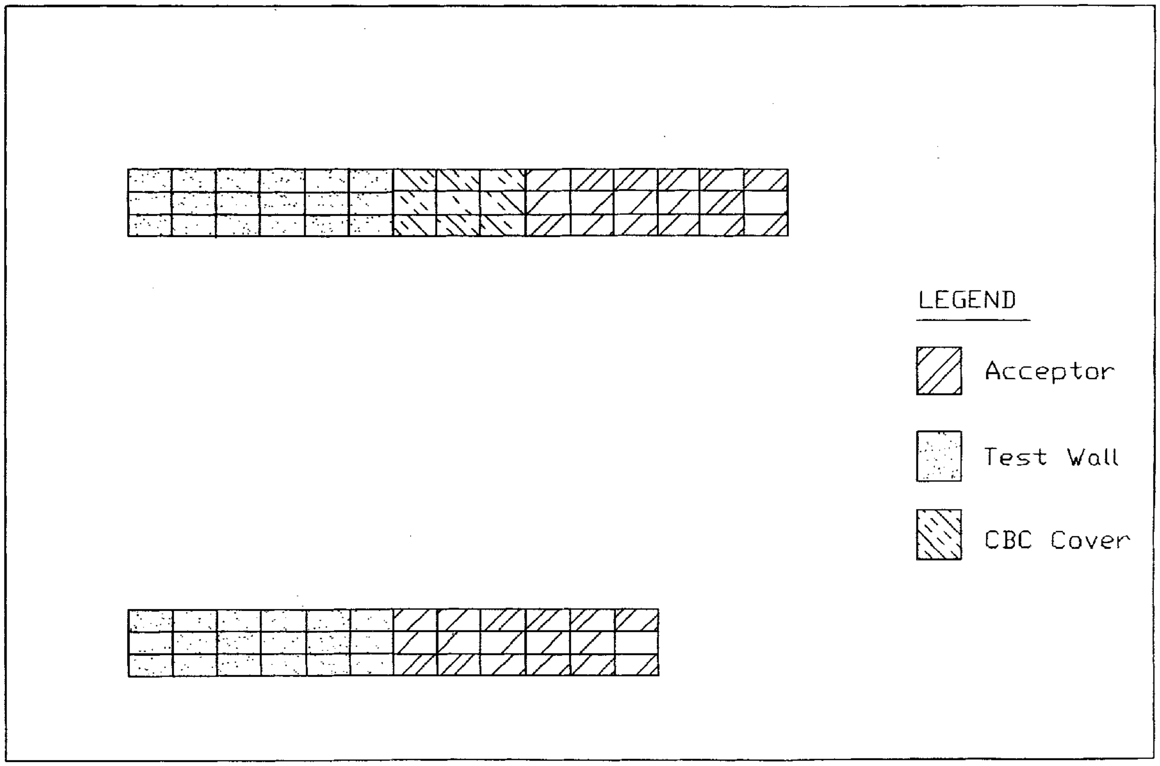


Figure 5. AUTODYN-2D One-Dimensional Model Setup.

Figure 6. One-Third Scale Acceleration Measurements.

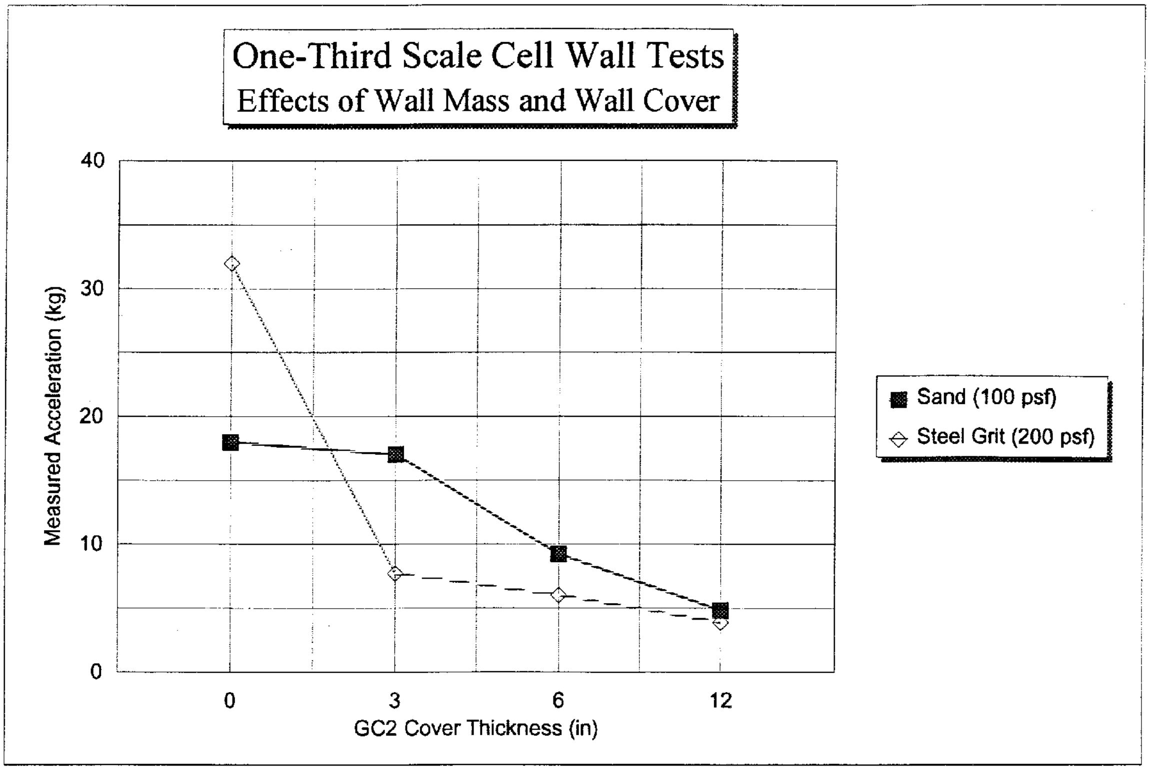


Figure 6. One-Third Scale Acceleration Measurements.

Figure 7a. HPM Full-Scale Cell Wall Test #1 - Test Setup.

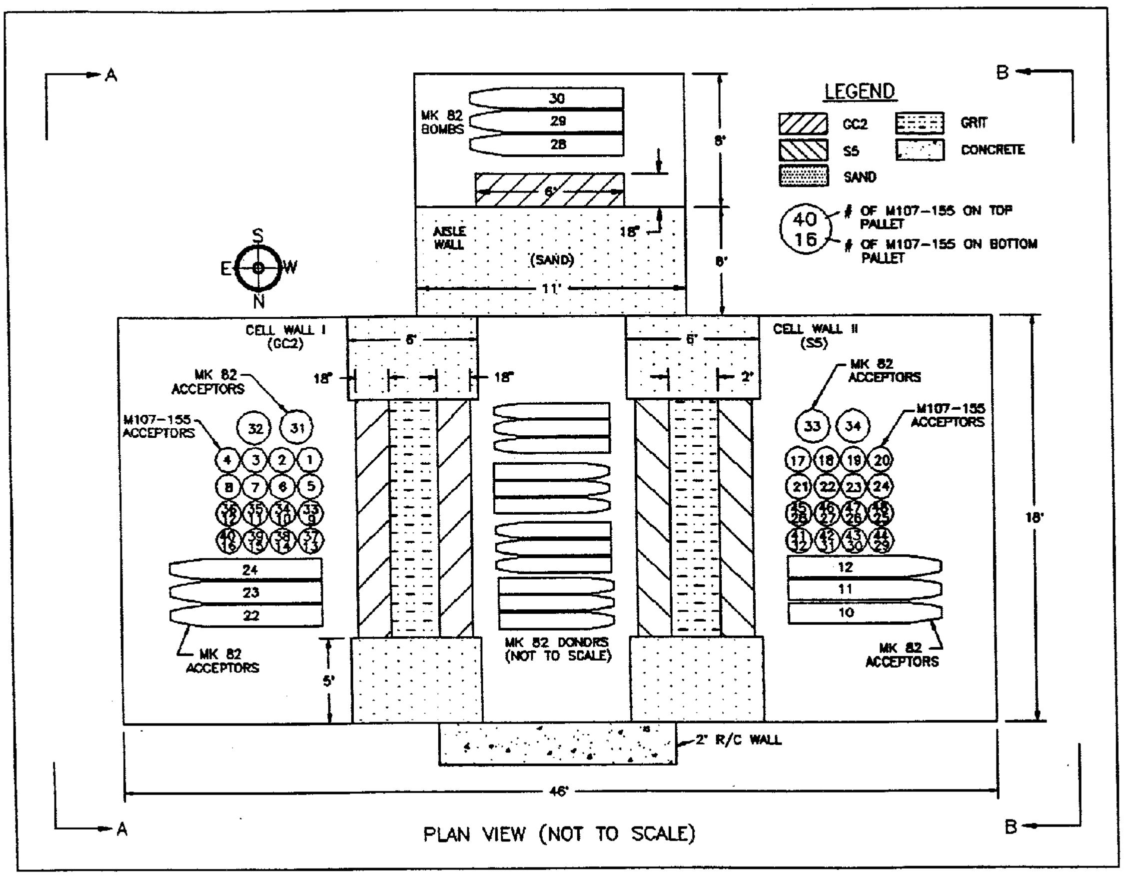
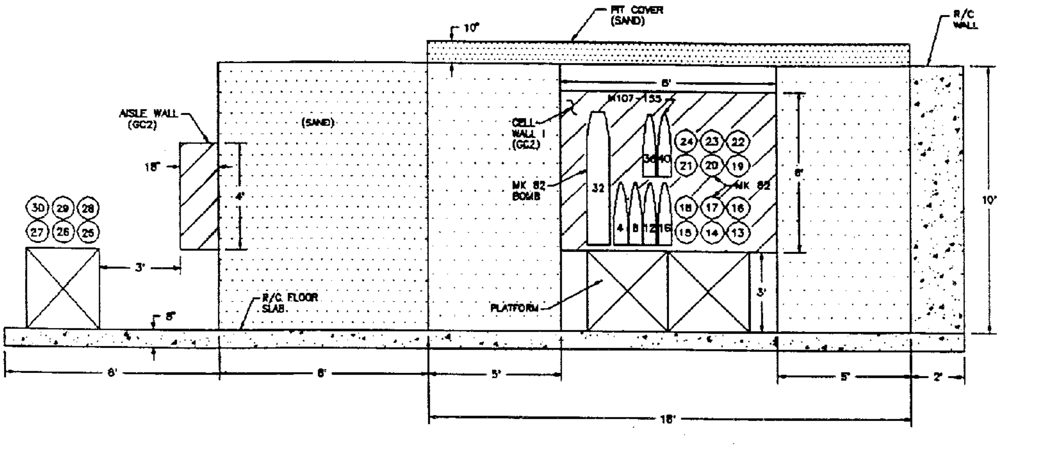


Figure 7a. HPM Full Scale Cell Wall Test #1 - Test Setup.

Figure 7b. HPM Full-Scale Cell Wall Test #1 - Test Setup.



Elevation — Section A-A

Figure 7b. HPM Full Scale Cell Wall Test #1 - Test Setup.

Figure 7c. HPM Full-Scale Cell Wall Test #1 - Test Setup.

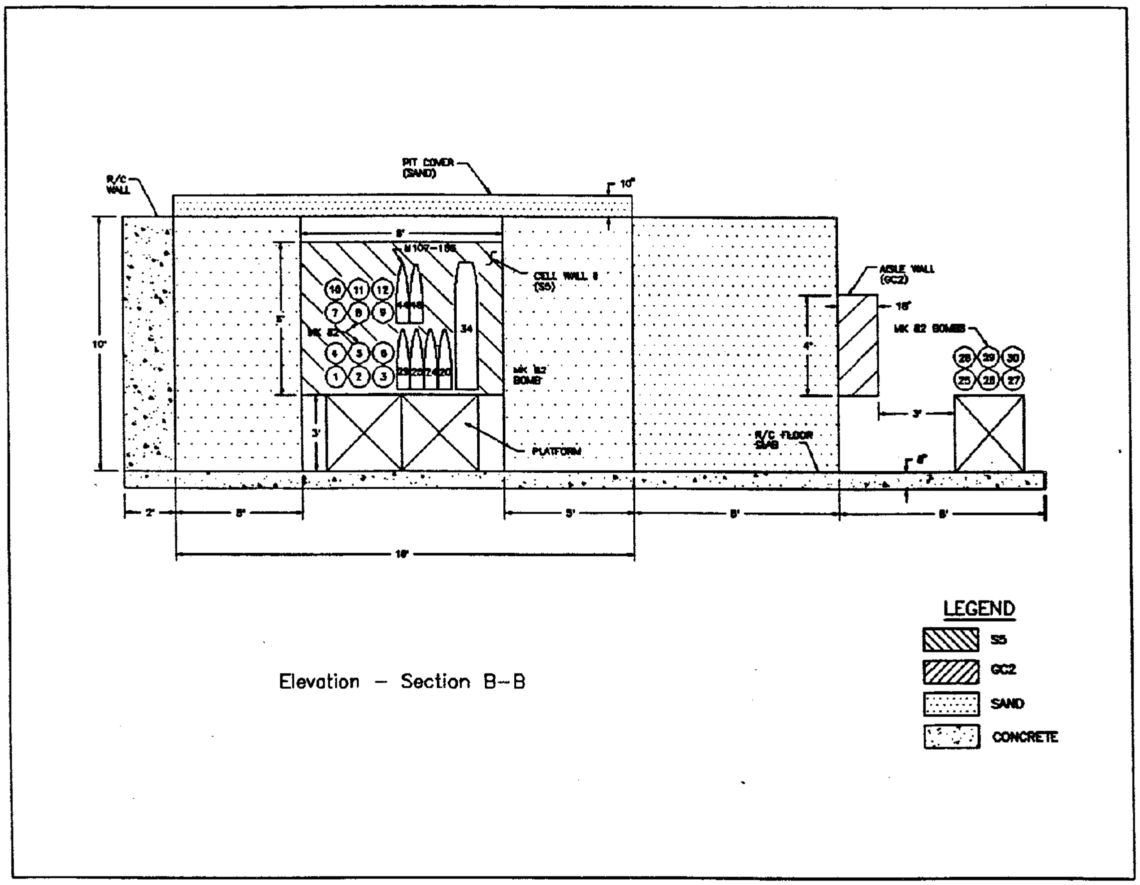


Figure 7c. HPM Full Scale Cell Wall Test #1 - Test Setup.

Figure 8a. HPM Full-Scale Cell Wall Test #2 - Test Setup.

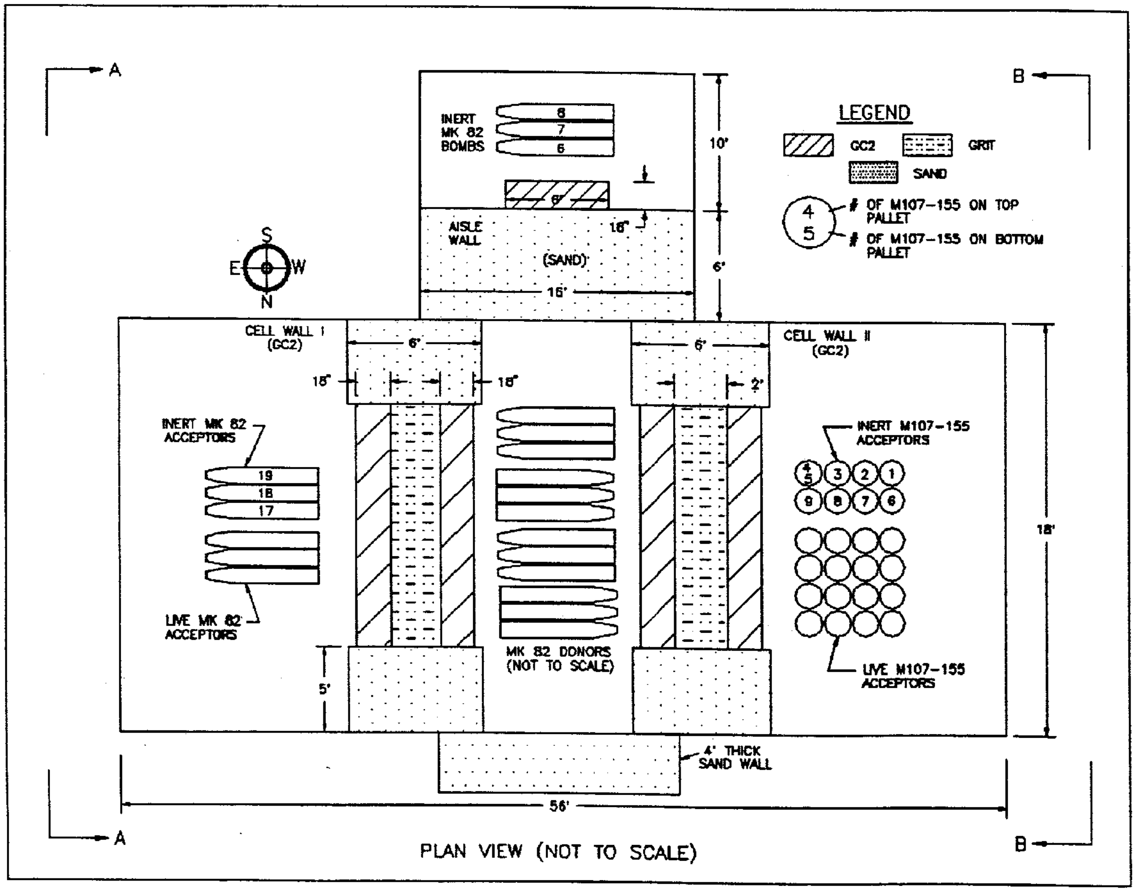


Figure 8a. HPM Full Scale Cell Wall Test #2 - Test Setup.

Figure 8b. HPM Full-Scale Cell Wall Test #2 - Test Setup.

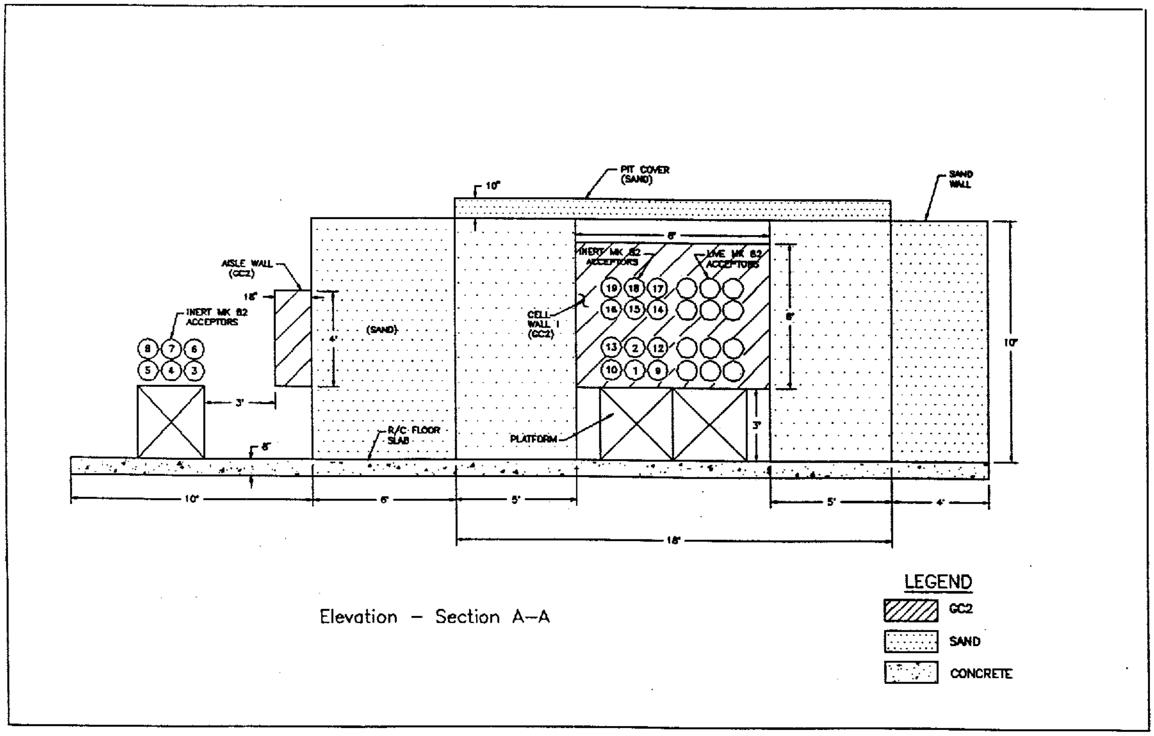


Figure 8b. HPM Full Scale Cell Wall Test #2 - Test Setup.

Figure 8c. HPM Full-Scale Cell Wall Test #2 - Test Setup.

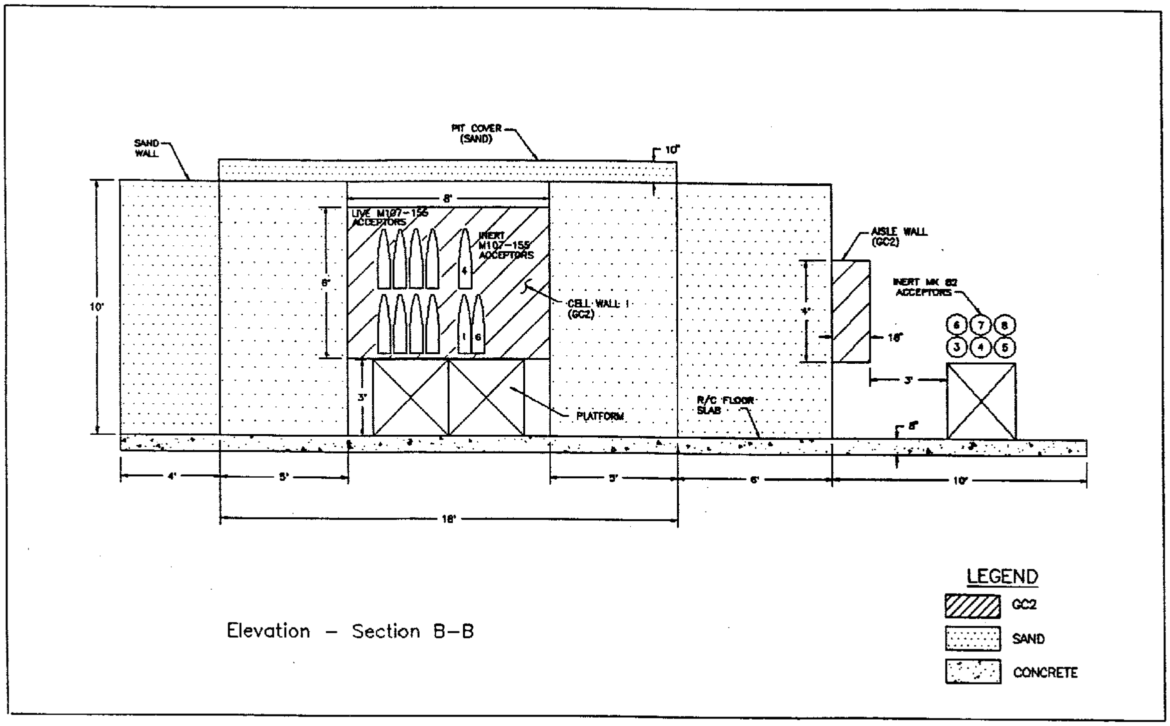


Figure 8c. HPM Full Scale Cell Wall Test #2 - Test Setup.

Figure 9. AUTODYN Model for HPM Full-Scale Wall Test.

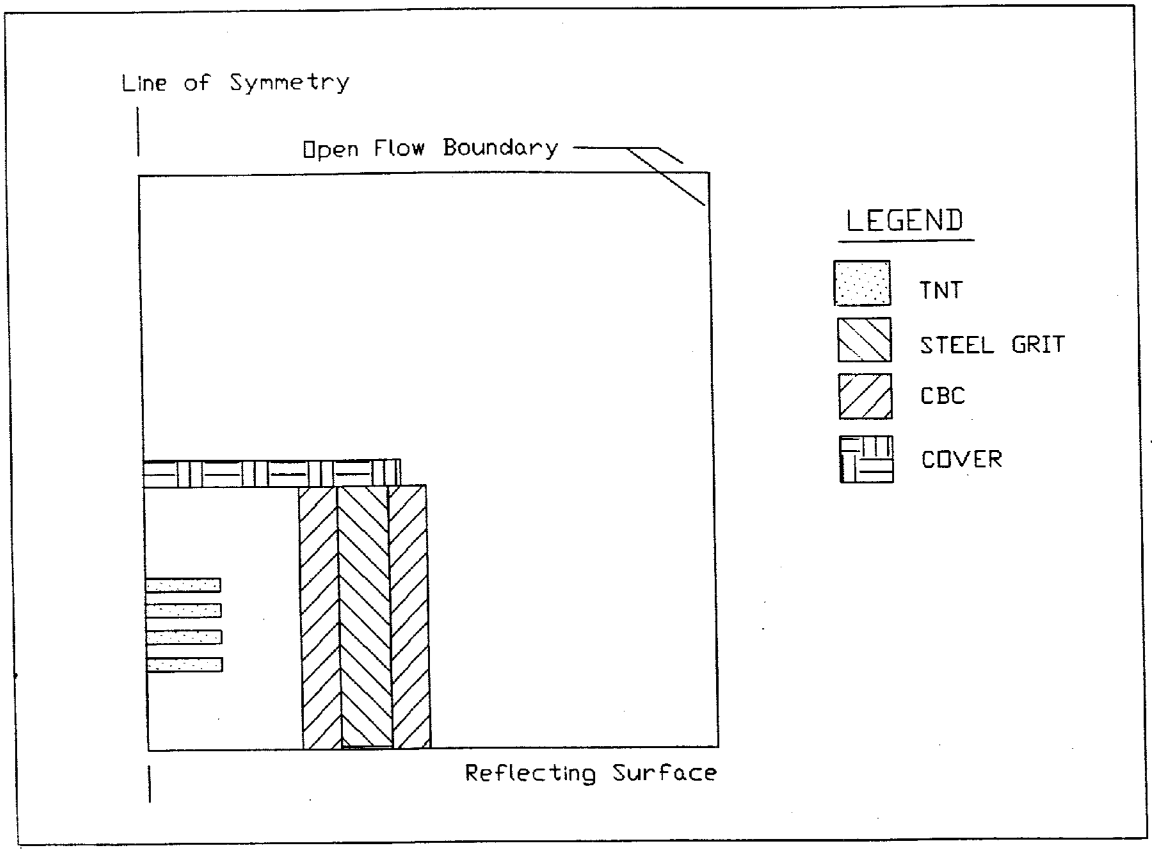


Figure 9. AUTODYN Model for HPM Full Scale Wall Test.

Figure 10a. Certification Test Structure No. 1: Floor Plan.

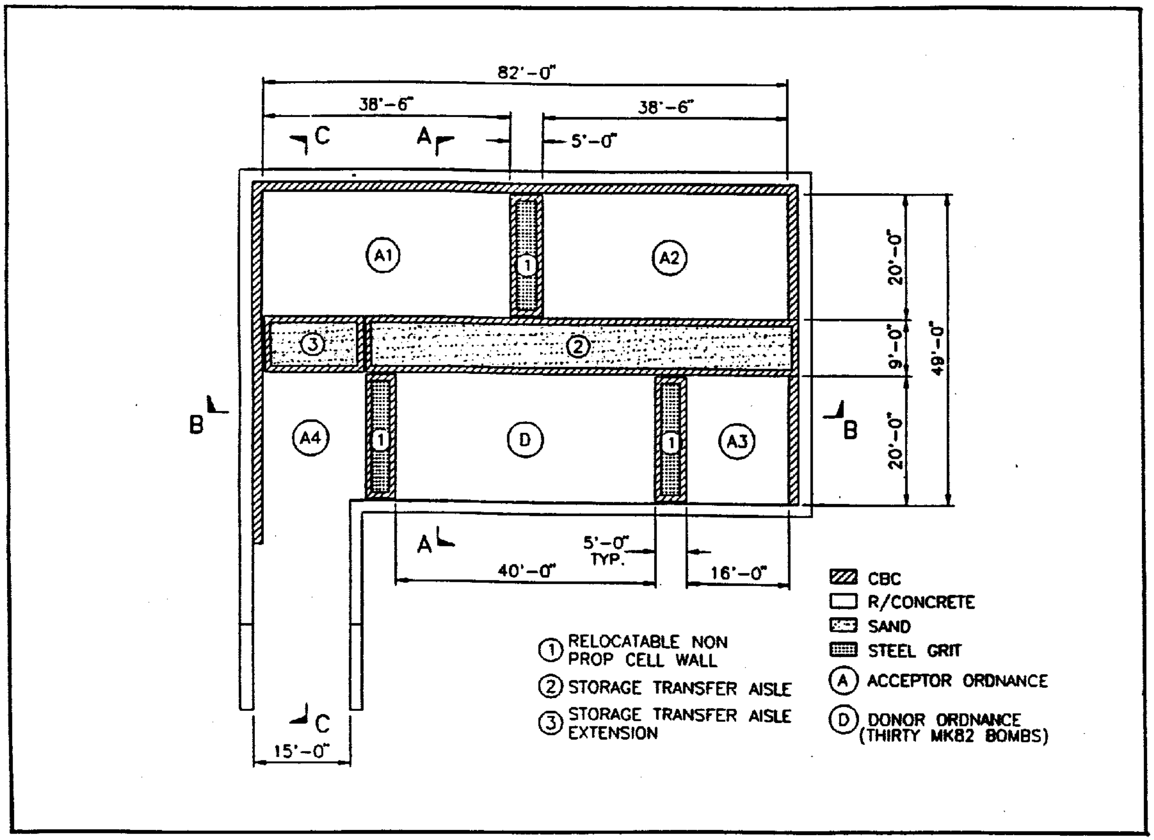


Figure 10a. Certification Test Structure No. 1: Floor Plan.

Figure 10b. Certification Test Structure No. 1: Section A-A.

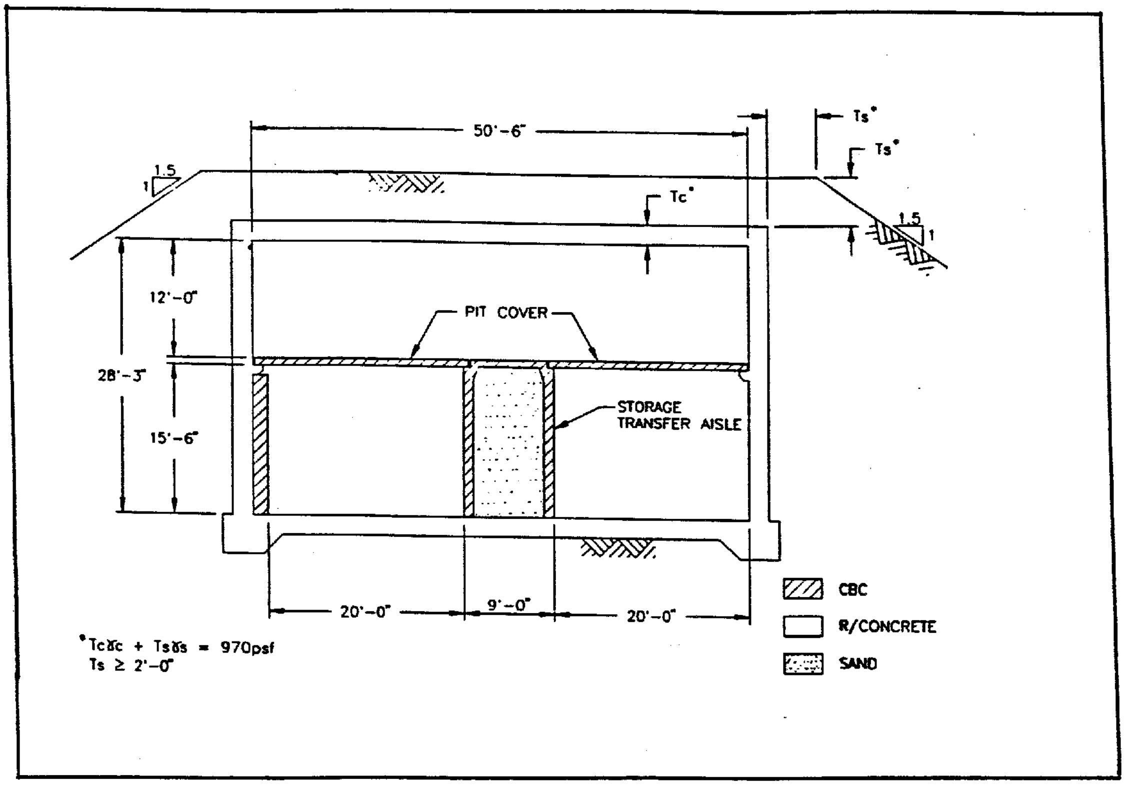


Figure 10b. Certification Test Structure No. 1: Section A-A.

Figure 11. AUTODYN Model of Certification Test.

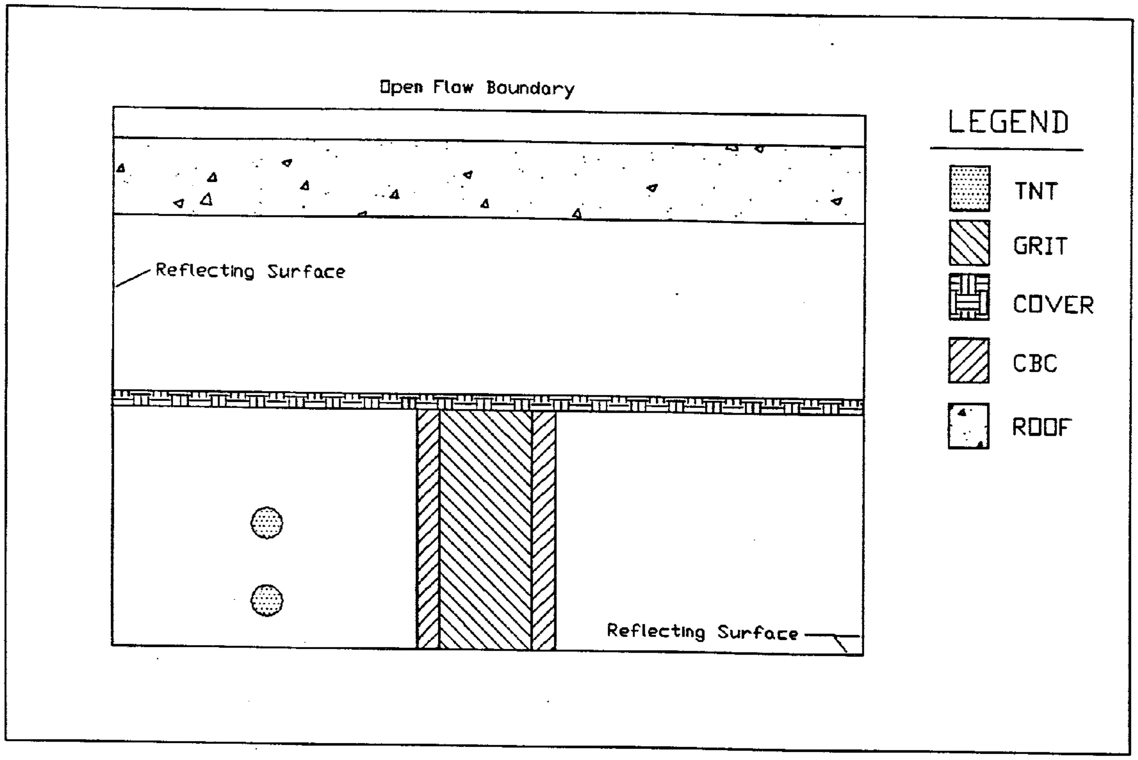


Figure 11. AUTODYN Model of HPM Certification Test.